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OPTICAL FIBER COMMUNICATIONS CABLE CONNECTOR. (U)
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OPTICAL FIBER COMMUNICATIONS CABLE CONNECTOR.

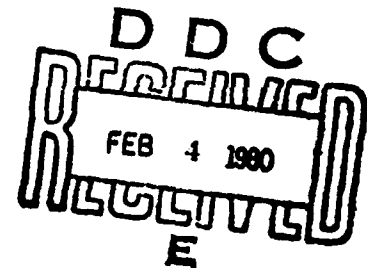
James F. Ryley

TRW INC.
Eastern Research Laboratories
Philadelphia, PA.

January 1980

Semi-Annual Report for Period 1 May - 1 Nov 79

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CORADCOM
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Fort Monmouth, New Jersey 07703

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Progress toward development of a multi-fiber, hermaphroditic, fiber optic cable connector is described. A brief survey of general approaches to fiber optic alignment schemes along with the present approaches philosophy is presented. Development status on the fiber alignment guide and preliminary connector design is summarized. Efforts toward developing a suitable fiber scribing machine for six fiber cable are introduced and future plans stated. | | |

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PREFACE

This semi-annual report describes work performed for The Center for Communications Systems, Multi-Channel Transmission Division of CORADCOM by The TRW, Inc., Eastern Research Labs under Contract DAAK 80-79-C-0772 awarded from Ft. Monmouth, New Jersey. The effort is directed towards fulfilling objectives of Technical Guidelines for Development of "Optical Fiber Communications Cable Connectors", dated June 1978 and in general support of the U.S. Army's Fiber Optic Development Program.

The Cinch Connector Division of TRW, Inc. is supporting this effort through mechanical design and fabrication assistance.

The period covered by this report is 30 April 79 to 30 October 79.

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I. INTRODUCTION

This report describes progress toward the development of a six channel, hermaphroditic fiber optic cable connector for military communications applications. The efforts and investigations being conducted are in general agreement with those proposed to meet the objectives of the Technical Guidelines (Appendix A) of the U.S. Army.

Three basic areas of investigation are included within this effort: The development and optimization of a fiber alignment technique, the development of a suitable fiber optic cable housing, and the design and perfection of complimentary fiber preparation and connector assembly tools. During the period covered by this report work in all three areas has been performed and a preliminary connector design has evolved.

II. FIBER ALIGNMENT

1. Background

Connectors for joining lengths of optical communications fiber in the field must provide low loss, and rapid, but reproducible connections. Three basic alignment criteria must be met before reliably low insertion losses can be realized, and these relate to the mutual attitude of the fiber ends to be joined. Axial alignment or lateral alignment as it is otherwise known, is the most critical parameter and often the most difficult to control. Slight offset between the two fiber ends dramatically increases optical loss. Gap loss, which is the loss incurred by mutual fiber face end separation, is the second parameter directly affecting connection loss. The severity of loss versus fiber gap is a function of the fiber numerical aperture. The third factor, and one which combines aspects of axial alignment and gap loss, is angular alignment. This parameter correlates connector insertion loss with the angle between the axes of the two mated fibers. Insertion losses on the order of 0.3 dB per mated pair represent the best result possible. This is because reflections occur at optical interfaces where there is a change in refractive index. For the silica-air-silica differential of approximately 0.46, encountered in fiber systems, it is these inescapable "Fresnel" reflections that give rise to the loss referred to. Such losses can of course be eradicated by elimination of the refractive index "step". This is achieved by use of an index matching medium between the two fiber ends. Liquids and epoxies for this purpose do exist. However, certain drawbacks are inherent where liquids are employed, the principal of which are containment and the adhesion of foreign, light scattering, particles. Reproducibly good connector performance must incorporate all aspects of high tolerance physical alignment with carefully prepared fiber ends.

2. State-Of-The-Art

Many methods have been proposed for aligning optical fibers and all quite naturally possess certain strengths and weaknesses. Broadly speaking, connector designs fall into one of three main categories: Ferrule-type, V-groove type, or lens type.

The ferrule approach seeks to align fibers by guiding them into the opposite ends of a closely fitting tube. The advantages are inescapable: The fibers cannot possibly misalign laterally or angularly so that only the gap must be controlled in order to achieve a low insertion loss. Disadvantages arise from the need for dimensional tolerance since real life experience has shown that such a device must be able to accept a range of fiber sizes. In making the tube large enough for the biggest fiber, it follows that the smallest fiber will experience slack within the tube. This condition introduces the potential for vibration-induced signal fluctuation and possible physical fiber degradation.

V-groove fiber alignment has found acceptance with the Bell Labs multiple fiber splice, where finely scribed wafers are layered to trap mutually opposed fibers, and also in the hermaphroditic Amp "overlap" design which uses elastomeric V-grooves to cause axial fiber alignment. Precision in manufacturing and fiber placement with regard to end separation are the critical features relevant to this concept.

The possibility of capturing all of the available signal which emerges from an emitting fiber by focussing it into an appropriately placed receptor fiber is the basis for the third major area of fiber interconnection, the lens approach. Devices of this type have been fabricated by the Japanese using "Selfoc" glass lenses. Disadvantages stem from alignment sensitivity and the

now essentially doubled Fresnel reflection loss. Nonetheless, this method does obviate one potential drawback of the ferrule and V-groove concepts, namely fiber gapping. Interfiber distance is extremely critical in that fiber-to-fiber contact can result in physical and optical degradation brought about by relative fiber movement, and yet too great a spacing will accrue intolerable losses.

3. TRW Alignment Guide

The TRW fiber alignment technique may be thought of as a combination of the ferrule and V-groove methods. Candidate fibers are introduced into the opposite ends of a smooth channel which has been created by fusing either three or four glass rods along their cylindrical surfaces to form a triangular or square rod cluster. The interstitial channel is terminated at each end by a conical flare taper to allow ease of fiber access. In that the channel is some forty percent larger than the fibers to be mated, the guide closely resembles a low tolerance ferrule-type connector at this point. However, each end of the guide has an off-axis bend, extending for about one quarter of the total body length and at an angle of approximately six degrees. Both bends are in the same relative direction, giving the appearance of an angular bow (Figure 1).



Figure 1: TRW alignment guide profile..

The purpose of the bend, or "elbow" is twofold. Firstly, the bend deflects a penetrating fiber so that it is biased to one side of the channel.

The design is such that this side is made up of the V-groove formed between two of the constituent glass rods. (Figure 2) The naturally high elasticity of the fiber ensures its adherence to the V-groove as it moves along the central straight section toward the guide mid point. This straight mid section is long enough to allow the curving fiber to adopt a parallel position with respect to the glass rods. This guide geometry assures that the two mating fibers approach one another at the mid point of the housing aligned both axially and angularly. This just leaves the fiber gap to be defined which brings up the discussion to the second reason for the "elbow".

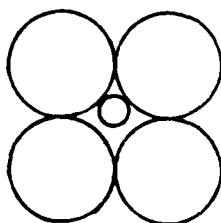


Figure 2: Four rod cross sectional view showing fiber in upper V-groove.

The optimum optical fiber-fiber gap is obviously zero, but this prospect immediately conjures up the prospect of damage from vibration and repeated fiber-fiber contact during connector mating. However, the same feature which deflects the fiber ends into a unique V-groove also deflects the externally protruding portions of the fibers away from the axis of approach and thereby creates a slight bow in the fibers at each end of the glass rod guide. (Figure 3) This predisposition for the fibers to bend gives rise to an automatic strain relief system. That is, the extent to which one fiber end can exert axial force on the other is strictly limited by the deflection in the fiber shafts just outside of the glass rod guide. This feature also means that inadvertently over length fibers do not necessarily precipitate

catastrophic failure. Instead, the fibers merely buckle to a greater extent, thereby accommodating the excess fiber. Possible damage inflicted by vibration is also obviated by the high rigidity modulus of the fiber. The force with which the fiber drives itself into the V-groove greatly exceeds that arising from any normally encountered vibrational accelerations.

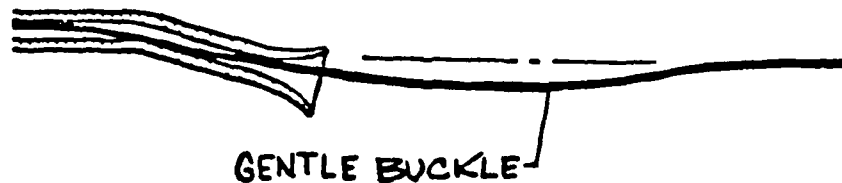


Figure 3: Inherent strain relief of TRW alignment concept.

4. TRW Guide Development

The four rod configuration has been selected over the 3 rod equivalent to minimize guide volume as well as due to its inherent vertical V-groove and greater ease of handling during fabrication. This four rod design has been optimized with respect to six inter-related parameters (Figure 4): D_F - fiber diameter, D_E - effective channel diameter, X -housing end section length, Y -housing mid-section half-length, θ -housing end section off-axis angle, and R -fiber radius of curvature. Manufacturing and handling considerations have also been taken into account. The interrelation of these quantities may be expressed as:

$$\theta = \frac{(D_E - D_F) [X^2 + (X + Y)^2]}{XY^2}$$

and

$$R = \frac{Y^2 + (D_E - D_F) D_E}{2 (D_E - D_F)}$$

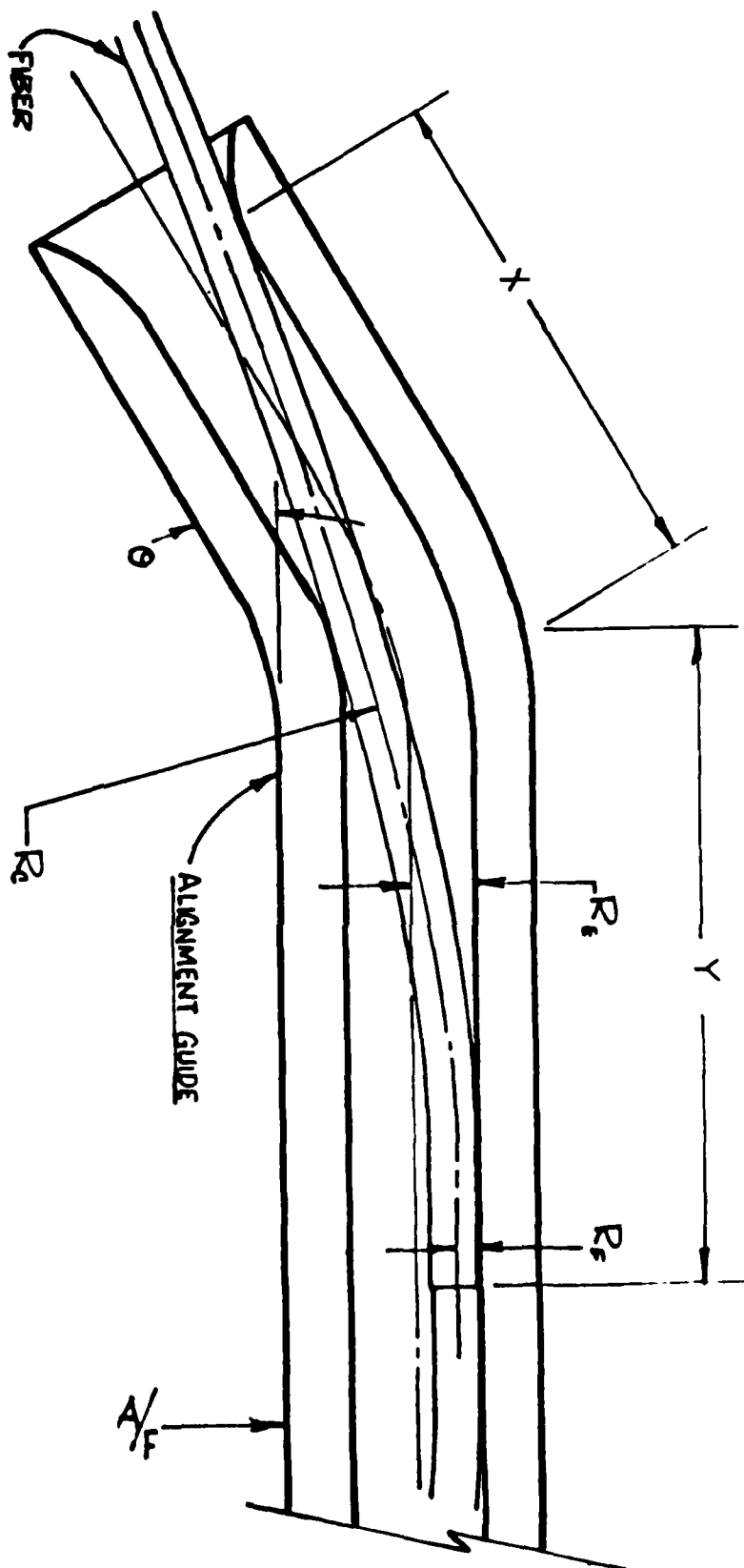


FIG. 4: ALIGNMENT GUIDE SCHEMATIC

- θ = ELBOW OFF-AXIS ANGLE
- X = ELBOW LENGTH
- Y = MID-SECTION LENGTH NECESSARY FOR FIBER AXIAL ALIGNMENT
- R_c = CHANNEL EFFECTIVE RADIUS
- R_f = FIBER RADIUS
- R_c = FIBER CURVATURE RADIUS
- A_f/F = FOUR ROD GUIDE ACROSS FLATS DIMENSION

Based on work done by Liertz¹ the Y dimension has been chosen to insure a maximum flexural stress of less than 80 N/mm^2 . This is to avoid fiber failure due to static fatigue. Assuming a Young's modulus of $6.9 \times 10^4 \text{ N/mm}^2$ and using equation 2* of Figure 4 we arrive at a minimum Y value of approximately 0.14 inches. The actual value used is 0.20 inches. This provides a 100% safety factor in R (fiber radius of curvature). Referring to equation 1 of Figure 4, it is advantageous to design for a small θ (for ease of fiber insertion, and a large value of $(D_E - D_F)$ again for insertion reasons. The function $\theta/(D_E - D_F)$ minimizes at approximately $Y = 2.36X$. Optimum X length is then 0.085 inches. For facility in manufacturing 0.100 has been used.

Alignment guides have been fabricated to this design and tested for insertion loss. Typical dimensions were:

$$X = 0.1''$$

$$Y = 0.2''$$

$$\text{lateral thickness} = 0.043'' \pm .002''$$

$$\theta = 6^\circ \pm 1/2^\circ$$

$$\text{overall length} = .747'' \pm .003''$$

Test results indicate an average insertion loss of 0.55 dB. In view of the use of a Y value greater than the minimum and fibers purposely scribed over-length to insure contact it was also necessary to investigate the effects of fiber overtravel and fiber mating position on the insertion loss. The results of these experiments are presented in Figures 5 and 6, respectively. It can be seen from Figure 5 that up to .025 inches overtravel has no effect on the overall insertion loss. Furthermore Figure 6 shows the guide to have an insensitive region to mating location of about 0.160 inches. This allows for a great deal of forgiveness in fiber scribing accuracy.

¹ Liertz, H., The Aging of Optical Waveguides, Electro-Optical Systems Design, June 1978.

* Values of $\theta = 6^\circ$, $D_E = 10 \text{ mils}$ have been used. They were arrived at through experimental investigations into the minimum dimensions necessary for fiber insertion without binding. D_F is, of course, 5.5 mils.

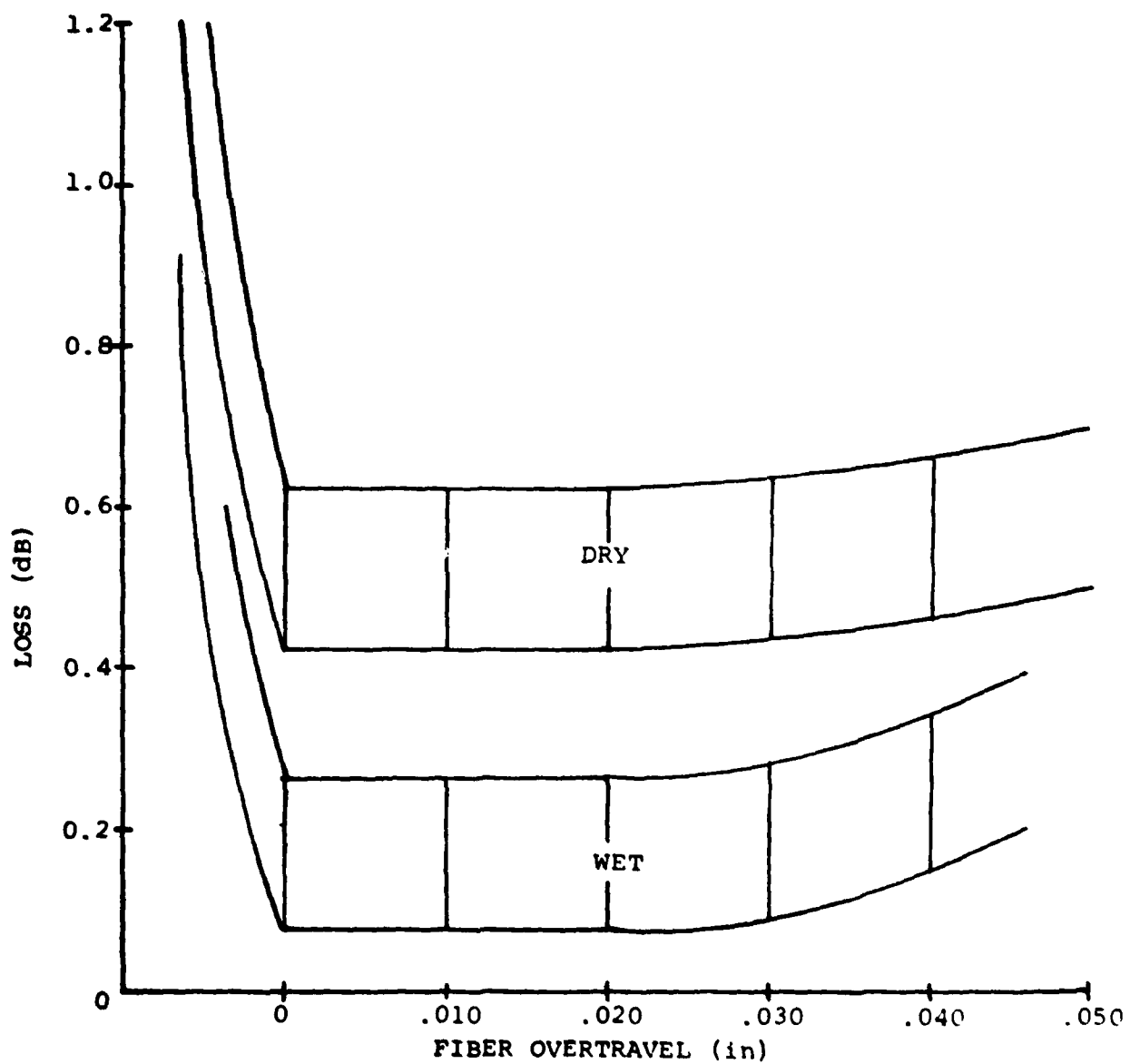


Figure 5 : Insertion loss versus fiber overtravel.

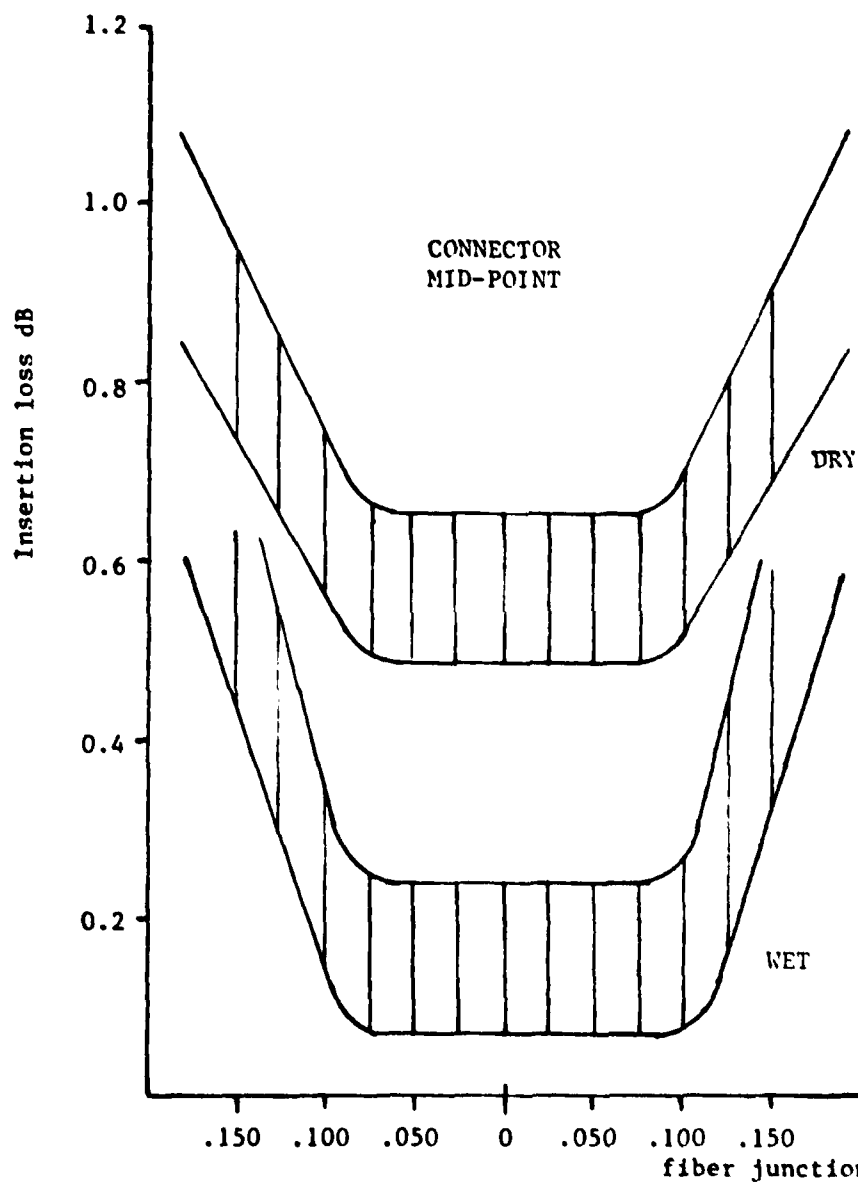


Figure 6: Light transmission vs fiber junction position
(fiber overtravel maintained at .000 - .005).

The production problems associated with these dimensions have been brought under control. The new $6\frac{1}{2}^{\circ}$ precision forming boats are now being used. Evaluation shows the average angle produced to be exactly 6° with only 8% falling outside the proposed tolerance of $\pm\frac{1}{2}^{\circ}$, and all parts meeting the present tolerance of $\pm 1^{\circ}$. The problem of bowing in the center section has virtually been eliminated with the precision design. Guide cleaning problems have also been overcome. These problems were of two kinds: 1) glass chips from the cutting process and, 2) graphite particles from the heat forming process. The cleaning process is done in two steps; a 20% NaOH solution for tungsten particles (from flaring tool) and a commercial soap for glass chips and graphite particles.

5. Fiber Scribe Machine

Design of a fiber scribing machine to compliment the six fiber connector has commenced. Original concepts feature 2 scribing blades, one for each required fiber length. The fiber will be held at one end by a mount designed to hold the fiber clamp support structure (mentioned above), and at the other by a metal clamping mechanism with teflon (or similar material) faces. The metal clamping mechanism will also automatically provide the prescribed fiber tension as the scribe blade is brought across the fiber. The clamp support mechanism will then be released and rotated for the next scribe.

III. CONNECTOR DESIGN

The basic connector design is currently in its second iteration. The present configuration differing from the original configuration in the cable/strength member securement method. The connector (Figure 7) will be of the rear assembly type. Cable to connector strength will be provided by clamping the Kevlar members. The same piece (1) that clamps the Kevlar also threads onto the cable jacket providing additional strength and sealing. This piece is then secured in another plastic part (2) that serves as both a means of spreading the individual fiber/buffer jacket strands (4) and as a support for the six fiber clamps (3). The buffer jackets are terminated in the back of the fiber clamps where they are secured by means of a rubber bushing. The rubber bushing, as well as the dimensions of this piece, are designed specifically to avoid microbend losses. The bare fibers then proceed through the clamps and are scribed to appropriate lengths. The clamping losses range from .1 to .2 dB for Lexan clamps. A single cylinder (5) houses three fiber alignment guide slugs (6) and three piston/spring sets (7) in much the same way a revolver cylinder houses bullets. The cylinder and clamp support are then snapped together via a central post precluding the loss of any parts from either piece. This cylinder registers against a shoulder in the connector shell (the shell acts as the positive stop). All other parts are registered off this cylinder. The two connector halves can be mated by either of the half's coupling nuts (8). If both nuts are used together with a number of O-rings, the connector can be completely sealed against the environment. The mated pair is slightly over seven inches long and less than two inches in diameter.

This design has been reviewed and approved by CORADCOM personnel for prototype fabrication.

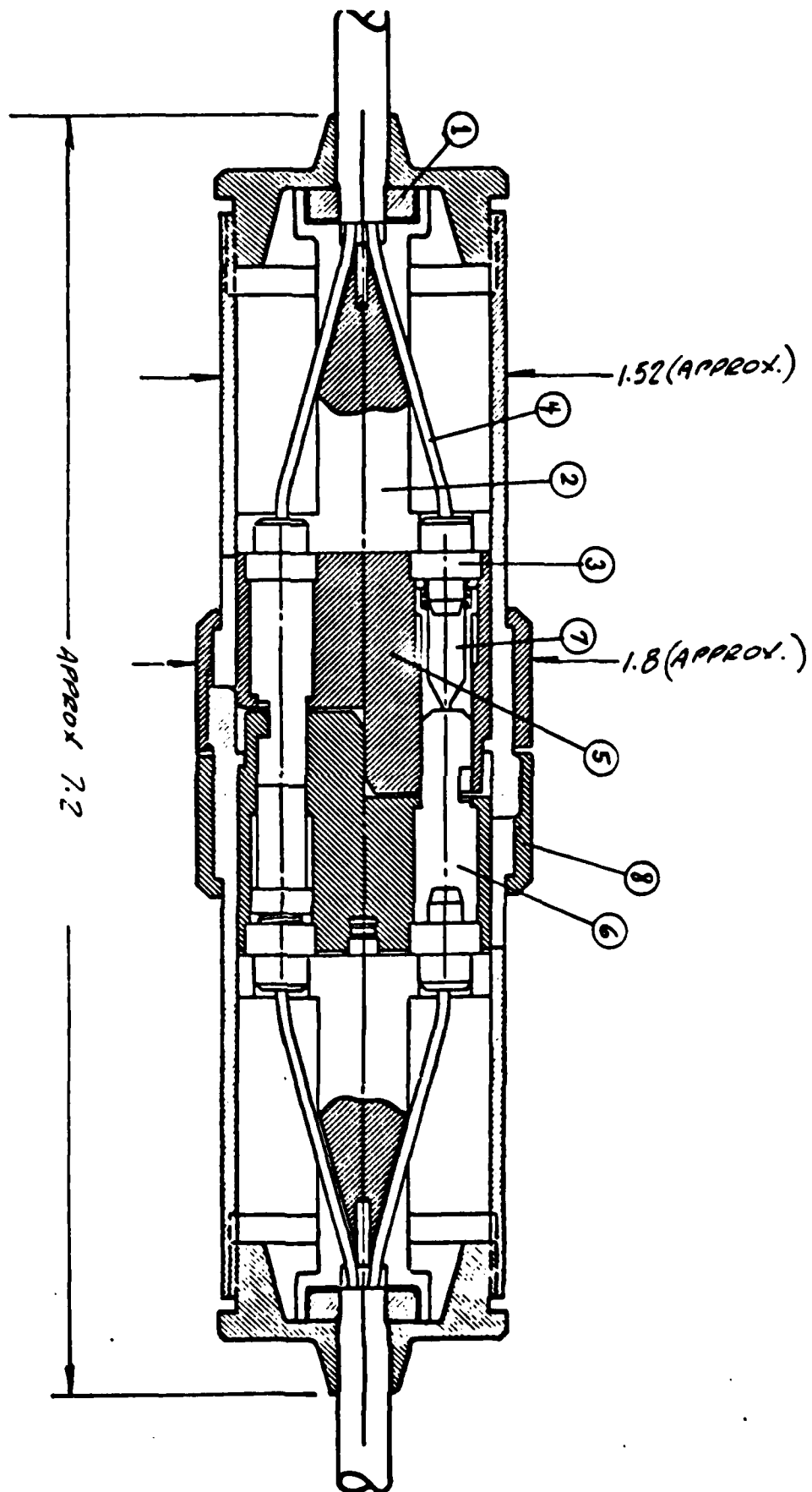


Figure 7: Design layout of six fiber communications connector.

IV. CONTRACT ADMINISTRATION

1. Performance Decisions

Through a number of meetings between Ft. Monmouth and TRW, Inc. personnel a number of agreements have been reached which are not clearly delineated within the contract document. These are as follows:

- 1) Of the 4 bulkhead and 6 plug connector halves to be delivered 1 bulkhead and 3 plug halves will be tested by TRW. The remainder will be tested by Mitre Corp.
- 2) The ability to remove fibers from the connector individually (for replacement by pigtailed LED, etc.) is not within the contract scope.
- 3) The Ft. Monmouth preference for ITT cable, which uses a non-concentric fiber coating, would require the stripping and recoating of the fiber ends for use in our alignment guide.*

* Contract change orders have been submitted in regard to point 3) above. Copies of the cover letter and DD form 633-5 as submitted are included as attachments to this report.

V. FUTURE ACTIVITIES

1. Fiber recoating effort as described in the attached contract change proposal.
2. Preliminary testing of the first prototype connector will begin based on the test plan, initially approved design, and by necessity will include Corning fibers. Revision and further testing will lead to the final design for a six channel hermaphroditic fiber optic communications connector.
3. In accordance with contract requirements a draft connector test plan is under preparation and will be submitted within November 1979.

ATTACHMENT

Contract Change Proposal

Contract #DAAK 80-79-C-0072

Re: Change from Siecor to ITT Fiber

Six Fiber Communications Connector

The alignment mechanism to be employed in the TRW six fiber connector depends on the concentricity of the fiber coating for maximum signal transmission. The original unsolicited proposal was predicated on the use of Corning fiber which presents such a coating. In the ensuing period it has been suggested that we use ITT fiber for more accurate comparison with connectors developed under similar contracts. This fiber does not offer the concentricity necessary for our alignment scheme. It is proposed here that, if the ITT fiber is to be used, an effort towards the development of a stripping and recoating method for the fiber ends be funded as an engineering change to the original contract.

The proposed method is to mechanically strip the original silicone coating under cover of the recoating lacquer. This affords two advantages: 1) the strip/recoat process is reduced to a one step operation, and 2) the bare (stripped) fiber is never exposed to the atmosphere. This latter aspect is very important as this exposure can weaken the fiber resulting in eventual catastrophic failure. Preliminary investigations indicate that this method is viable.

The change would include the design, production and subsequent perfection of the stripping/recoating apparatus (Figure 1), as well as the selection and testing of various coating materials. The proposed cost of such an effort is \$20,220. The details of this figure are attached together with form DD 633-5. Estimated time to completion is 6 months calendar time.

**DEPARTMENT OF DEFENSE
CONTRACT PRICING PROPOSAL(CHANGE ORDERS)**

Form Approved
Budget Bureau No. 22R0165

This form is for use when submission of cost or pricing data (see ASPR J-807.3) is required.

PAGE NUMBER

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NUMBER OF PAGES

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NAME OF CONTRACTOR

TRW, Inc.

PRODUCT IDENTIFICATION

Six Fiber Communications Connector

HOME OFFICE ADDRESS (Include ZIP Code)

2355 Euclid Avenue
Cleveland, Ohio 44117

MODEL OR PART NUMBER

NUMBER OF UNITS AFFECTED

DIVISION(S) AND LOCATION(S) WHERE WORK IS TO BE PERFORMED

Eastern Research Labs
401 N. Broad St., Phila., Pa. 19108

CONTRACT NUMBER

DAAK80-79-C-0072

CHANGE IDENTIFICATION

0772-1

PROPOSED CHANGE ESTIMATE

| COST ELEMENTS | | COST OF WORK DELETED | | | COST OF WORK ADDED ⁵ | NET COST OF CHANGE ⁶ | REF.ERENCE ⁷ |
|--------------------|------------------------------------------------------------------|-------------------------------------------------|-----------------------------------------------------|-------------------------------------|---------------------------------|---------------------------------|-------------------------|
| | | ESTIMATED COST OF ALL DELETED WORK ² | COST OF DELETED WORK ALREADY PERFORMED ³ | NET COST TO BE DELETED ⁴ | | | |
| 1. DIRECT MATERIAL | a. PURCHASED PARTS ⁹ | | | | 500.00 | | 1 |
| | b. SUBCONTRACTED ITEMS ¹⁰ | | | | 5000.00 | | 2 |
| | (1) RAW MATERIAL ¹¹ | | | | | | |
| | (2) STANDARD COMMERCIAL ITEMS ¹² | | | | | | |
| | (3) INTERDIVISIONAL TRANSFERS (At other than cost) ¹³ | | | | | | |
| 2. | MATERIAL OVERHEAD ¹⁴ | | | | | | |
| 3. | INTERDIVISIONAL TRANSFERS AT COST ¹⁵ | | | | | | |
| 4. | DIRECT ENGINEERING LABOR ¹⁶ | | | | 5192.32 | | 3 |
| 5. | ENGINEERING OVERHEAD ¹⁴ | | | | 8307.71 | | 3 |
| 6. | DIRECT MANUFACTURING LABOR ¹⁶ | | | | | | |
| 7. | MANUFACTURING OVERHEAD ¹⁴ | | | | | | |
| 8. | OTHER COSTS ¹⁷ | | | | | | |
| 9. | SUBTOTALS | | | | | | |
| 10. | GENERAL AND ADMINISTRATIVE EXPENSES ¹⁴ | | | | | | |
| 11. | ROYALTIES ¹⁸ | | | | | | |
| 12. | FEDERAL EXCISE TAX ¹⁹ | | | | | | |
| 13. | SUBTOTALS | | | | | | |
| 14. | PROFIT OR FEE 8% | | | | 1520.00 | | |
| 15. | TOTAL PRICE (Amount) | | | | 20520.03 | | |

I. WILL THE AMOUNT OF GOVERNMENT PROPERTY REQUIRED IN THE PERFORMANCE OF THIS CONTRACT BE REVISED DUE TO THIS CHANGE?

☐ YES ☐ NO IF YES, IDENTIFY ON A SEPARATE PAGE.

II. DID YOU COMPUTE "ESTIMATED COST OF ALL WORK DELETED" IN ACCORDANCE WITH FOOTNOTE 3?

☐ YES ☐ NO IF NO, EXPLAIN AND JUSTIFY ON A SEPARATE PAGE.

III. DOES THIS COST SUMMARY CONFORM WITH THE COST PRINCIPLES SET FORTH IN ASPR, SECTION XV (see J-807.2(c)(3))?

☐ YES ☐ NO IF NO, EXPLAIN ON A SEPARATE PAGE.

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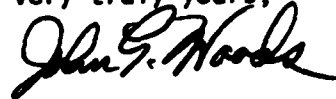
Gentlemen:

This is in reference to the Semi Annual Report, 1 May - 1 November 79, for Contract DAAK80-79-C-0772.

Attached is an Errata Sheet, as well as the appropriate substitution pages for the above report. It is suggested that the recipients of the report make the corrections listed on the Errata Sheet.

The report was inadvertently distributed in the original form. We apologize for any inconvenience incurred by this error.

Very truly yours,



John G. Woods
Research & Development Labs.

JGW/sf

80 4 10 028

ERRATA

CORADCOM-79-0772-1

Semi-Annual Report for Period 1 May - 1 November 1979

- a) Attach Appendix A, "Technical Guidelines" at the end of the report.
- b) In Table of Contents, DELETE the words: "Change Proposal Attachment" and SUBSTITUTE: "Appendix A, Technical Guidelines".
- c) REMOVE and destroy the "Change Proposal Attachment", as well as the "Contract Pricing Proposal (Change Orders)".
- d) On page 15, DELETE Item 1 of Section V.
- e) On page 14, DELETE the footnote.
- f) REMOVE, and discard, the cover sheet; SUBSTITUTE the new, heavier weight cover. It is suggested that the report be double stapled at the left hand edge.



RESEARCH AND DEVELOPMENT TECHNICAL REPORT
CORADCOM-CONTRACT NUMBER 79-0772-1

OPTICAL FIBER COMMUNICATIONS CABLE CONNECTOR

James F. Ryley
TRW INC.
Eastern Research Laboratories
Philadelphia, Pa.

January 1980

SEMI-ANNUAL REPORT FOR PERIOD
1 MAY- 1 NOV.-1979

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Prepared for:
CENCOMS

CORADCOM
US ARMY COMMUNICATIONS RESEARCH & DEVELOPMENT COMMAND
FORT MONMOUTH, NEW JERSEY 07703

NOTICES

Disclaimers

The citation of trade names and names of manufacturers in this report is not to be construed as official Government indorsement or approval of commercial products or services referenced herein.

Disposition

Destroy this report when it is no longer needed. Do not return it to the originator.

APPENDIX A

US ARMY COMMUNICATIONS RESEARCH & DEVELOPMENT COMMAND FORT MONMOUTH, NEW JERSEY 07703

Technical Guidelines

.. 14 June 1978

"Optical Fiber Communications Cable Connector"

1. Scope: These guidelines cover the development of connectors for use in tactical fiber optic cable communication systems. The connector must be hermaphroditic and provide optical mating faces with minimal coupling loss between mating connectors. The design must have the potential to withstand tactical field applications.

2. Applicable documents:

2.1 Issues of documents: The following documents of the issue in effect on date of invitation for bids or request for proposal form a part of these guidelines to the extent specified herein.

Specifications

Standards

MIL-STD-1373

Screw-Thread, Modified, 60° Stub, Double

MIL-STD-202

Test Methods for Electronic and Electrical Component Parts

MIL-STD-1678

Fiber Optic Test Methods and Instrumentation

3. Requirements:

3.1 Objective: The objective of this program is to develop connectors for use with cables containing up to six low loss optical fibers. The fibers shall be graded index type with attenuation under 10 dB/km at 820 nm. The connectors must demonstrate the potential to function in adverse environments typical of tactical field applications.

3.2 Investigation: Unique methods shall be investigated to achieve the coupling loss requirement of this specification. The approach shall minimize the dependence on precision machining of optical alignment parts and criticality of fiber placement along the longitudinal axis. In addition, the approach shall include, but not be limited to, the following considerations:

3.2.1 Field Repair: The objective is a connector design which is capable of assembly to the cable by trained technicians in a depot or mobile repair van. The design shall not require the use of molding or potting techniques for accomplishing the assembly.

3.2.2 Cable Preparation: Methods and techniques for preparation of the cable ends for proper assembly with the connector shall be established. This shall include details as to tools, processes, solvents, and stripping dimensions for removal of jacketing, encapsulants, and fiber coatings. Preparation of optical fiber ends to provide the most efficient optical surface shall also be addressed.

3.2.3 Cable Strain Relief: The connector design shall include a suitable cable strain relief. The optical fibers which are contained within the confines of the connector housing must be isolated from direct tensile and bending forces which are applied to the cable extending beyond the confines of the connector. Furthermore, the strain relief shall provide resistance to cable pullout and damage due to such tensile and bending forces.

3.2.4 Mating Characteristics: The mating faces of the connector shall be optical with minimal crosstalk between adjacent optical paths and coupling loss between connectors. The optical mating faces must be suitably protected to prevent permanent degradation of light transfer between mating connectors as a result of repeated matings and unmatings, and exposure to moisture, water immersion, dirt, dust, sand, salt spray, and temperature extremes. The mating surfaces shall be easily accessible for cleaning with water, dry cloth, or small brush. The connector mating face and positive locking-coupling device shall be complaly hermaphroditic to permit termination of both ends of the cable with identical connectors. The coupling device shall be free turning with respect to the connector shell. If a threaded coupling device is used, the threads shall be in accordance with Specification MIL-S-23747.

3.2.5 Bulkhead Receptacle: Bulkhead receptacles shall have essentially the same mating characteristics as cited in 3.2.4 except that the coupling device shall not be free turning with respect to the connector shell. A D-hole type mounting with jam-nut threads and sealing for panels up to 1/4-inch thick shall be provided. The receptacle shall contain provision for removal and insertion of individual optical fibers at the rear of the connector. The individual removable fibers shall be held firmly in place after insertion and be capable of being released for removal when required. This feature is required to provide coupling to light sources and detectors.

3.3 Performance Requirements:

3.3.1 Coupling Loss: The coupling loss of mated pairs of connectors shall not exceed 1.5 dB (under 1.0 dB is desired) on an ind'vidual optical channel

to channel basis when tested in accordance with paragraph 4.1.1

3.3.2 Rotation: The torque required to rotate the free-turning coupling nut shall not exceed 0.75 inch-pound when tested in accordance with paragraph 4.1.2.

3.3.3 Mating Durability: There shall be no visible damage to the connectors, and they shall meet the requirements of 3.3.1 and 3.3.2 when tested in accordance with paragraph 4.1.3.

3.3.4 Vibration: Optical coupling loss shall be maintained and the connectors shall remain mated with no loosening of the coupling device throughout the vibration cycling of paragraph 4.1.4. After the test is completed, there shall be no damage and/or loosening of parts, the connectors shall be mechanically operable, and shall meet the requirements of 3.3.1 and 3.3.2.

3.3.5 Thermal Shock: Optical coupling loss of mated connectors shall be maintained throughout the test specified in paragraph 4.1.5. After completion of the cycling, the connectors shall be capable of mating and shall meet the requirements of 3.3.1 and 3.3.2.

4. Quality Assurance Provisions:

4.1 Performance Testing: Unless otherwise specified, the test specimen shall consist of a connector assembled to a cable. The length of cable shall be the minimum length required for valid measurement of the optical properties (paragraph 3.3.1) and to enable analysis of the effects of the mechanical and environment tests (3.3.3 thru 3.3.5) on the optical properties. The attenuation of individual fibers of the cables shall be no greater than 10 dB/km. A test plan with detailed test methods including the cable lengths, connector types, test measurements, and instrumentation shall be provided to the government for approval prior to the start of the test program.

4.1.1 Coupling Loss: The coupling loss of mated connector pairs, when measured in accordance with the test plan, shall meet the requirements of paragraph 3.3.1.

4.1.2 Rotation: The torque required to turn the coupling nut of the connector shall be measured with a suitable torque wrench. The torque shall not exceed the requirement indicated in paragraph 3.3.2.

4.1.3 Mating Durability: The test specimens shall be subjected to 1000 complete cycles of mating and unmating. One cycle shall consist of complete engagement and disengagement of connectors. Lubrication of coupling devices is not permitted. Optical continuity shall be monitored throughout the cycling. At the completion of the 1000 cycles, the connector mating surfaces may be cleaned as indicated in paragraph 3.2.4 herein. There shall be no evidence of mechanical damage, and the specimens shall meet the requirements of paragraphs 3.3.1 and 3.3.2.

4.1.4 Vibration: The test specimens shall be subjected to the Vibration Test of MIL-STD-202, Method 204, Test Condition A. Optical coupling loss through the mated connectors shall be monitored throughout the test. The connectors shall meet the requirements of paragraph 3.3.4.

4.1.5 Thermal Shock: The test specimens shall be subjected to the Thermal Shock Test of MIL-STD-202, Method 107, Test Condition A. Optical coupling loss through the mated connectors shall be monitored throughout the test. The connectors shall meet the requirements of paragraph 3.3.5.

5. Preparation for Delivery:

5.1 Packaging, Packing, and Marking: Packaging, packing, and marking shall be as specified in the contract.

6. Notes:

MIL-STD-1678, "Fiber Optic Test Methods and Instrumentation" may be used as a guide for the performance of the tests indicated in these guidelines.